MUSCULAR CONTRACTILITY.

By JACOB REDDING, M. D., Falmouth, Ind.

[PLATE I.]

Notwithstanding the remarkable progress that has been made in physiology during the last half of the present century, we are still left in comparative darkness with regard to the source of the impulse by the exercise of which the phenomena of muscular movements are produced. Indeed the only substantial lesson taught in medical literature on this subject is one with which almost every school child is familiar, namely: Muscular tissue has the property of becoming shorter in the direction of its greatest length, under the influence of an exciting cause, and of returning to its former state when such influence is withdrawn, and that they may retain this property for some hours after coördinate vitality has ceased.

Now the question presents itself, can it be possible that the force, or forces, which determine muscular movements are of such an extremely subtle nature, or their manifestations so exceedingly peculiar and complex in character, as to completely elude the grasp of the finite mind?

Dr. Beale states, in his work on Bioplasm, that "no phenomena has been discovered in connection with the action of any of the tissues already considered, which at all resembles that which is the peculiar characteristic of muscle. In both muscle and nerve molecular changes remarkable for their rapidity and repetition, take place, the exact nature of which is still doubtful." And again, "the phenomena of contractility characteristic of this class of tissue is therefore probably due to changes in non-living formed material only, and is not in any way dependent upon bioplasm."

I am certainly a most ardent admirer of Dr. Beale; nevertheless, after careful and repeated examinations of both living and dead

muscle, also of bioplasm living and dead, confined and unconfined, limited and unlimited in its movements, I am forced to the conclusion that every muscular contraction is directly dependent upon active and forcible changes taking place in confined bioplasm; and, secondly, that muscular relaxation is dependent upon the flexible property of its formed material and passive changes occurring in living matter. Indeed, upon this hypothesis, and upon no other, can the occurrence of increased temperature after coördinate vitality has ceased, the occurrence of *rigor mortis* and all the peculiar phenomena connected therewith, as well as every other phenomenon connected with the muscular system, be satisfactorily and rationally explained.

It is stated that the movements of muscular tissue as regards direction, extent and place are limited and are determined by external forces, and that therefore these movements are essentially different from the movements of living matter, and cannot be classed together, since the movements of bioplasm result from the operation of "forces acting from within the matter itself;" nevertheless, we could, were it thought necessary, or even desirable, conclusively show that the phenomena of muscular movements do not harmonize with the ordinary operations of any one or more of the physical forces; that such an hypothesis fails to explain the differences existing between the warm-blooded and cold-blooded animals as regards the length of time during which they may respectively retain muscular irritability after respiration and circulation have ceased. It fails to explain what is really implied by the term "irritability;" it fails to explain the difference between the voluntary and involuntary muscular tissue, whereby the former is enabled to contract quickly, under an exciting influence, while the latter under precisely the same influence, contracts so much more slowly.

In short, such an hypothesis fails to satisfactorily explain any of the many phenomena connected with muscular movements, either during life, or after coördinate vitality has ceased. The chemical theory (which was formerly held in high esteem) would involve such a rapid structural disintegration and tissue formation as to not only astonish the world, but even Him who spoke it into existence.

In order that we may clearly comprehend what follows it will be necessary that we briefly inquire into the histological conformation of muscle.

We shall find then that the non-striated muscle cell is fusiform in shape, of transparent, refracting and amorphous formed material, and containing in its interior, at the point of its greatest diameter, an elongated, or rod-shaped nucleus, or bioplast. These cells are so united that the body of one is received between the attenuated extremeties of its four neighboring cells, thus forming fasciculi, or membranes. This description is equally applicable to the non-striated muscle of the warm- or the cold-blooded animal. Hence, "anatomical structure and constitution" being precisely the same, we are of necessity forced to attribute the remarkable difference in the length of time during which they respectively retain muscular irritability after respiration and circulation have ceased, to some other principle, condition, or influence.

A microscopal examination of striated muscle reveals the same identity of "anatomical structure and constitution" that was found to obtain in the former case, and hence the same remarks hold good as to it.

Unfortunately, however, histologists have been content with a superficial view of striated muscle cell, and have, therefore, come to the erroneous conclusion that these cells consist of *anatomical* structure only, and hence that they were devoid of a *constitution.*

I shall endeavor to show, however, that each and every individual striated muscle cell does possess a living, moving, interior *constistitution;* and, secondly, that herein lies the force, which is the source of the impulse by and through which the phenomena of muscular contractions are produced.

Voluntary muscle, then, consists, in its anatomical structure, of bundles of minute fibrillæ, enclosed in a membraneous sheath,—called the sarcolemma. The fibrillæ are composed of cells, averaging about one twelve-thousandth of an inch in length and one eighteen-thousandth of an inch in their transverse diameters, and joined end to end in a minute filament of variable length. It is by virtue of the union of these cells, end to end, that the transverse striation is produced, while the longitudinal marking results from the immediate juxtaposition of the ultimate fibrillæ themselves.

Thus far all are agreed; but what of the interior of these cells? Authors have completely ignored, or, at least, have remained silent upon this subject. And yet I think I am able to establish

beyond the power of successful contradiction, that the outer formed material, of perhaps a fibrous character, the cell wall, does contain in an anterior space a transparent, colorless, structureless, semi-fluid substance, which possesses all the properties of living matter; and that it is by virtue of a change in form taking place in this living matter that muscular contractions are produced.

Analogy teaches us that such is the case; for every organic cell, every anatomical unit, so to speak, is found upon investigation to contain a greater or less amount of bioplasm within its interior, so long as they are capable of performing an active function, or, in other words, unless they have undergone complete dessication. The epithelia, the endothelia, the non-striated muscle cells, the fat vessicles, all contain living matter in an interior space, and this has been dislodged in some instances, and has then been observed to undergo all the varied and peculiar movements characteristic of unconfined bioplasm. Moreover, there is no tissue or organ of the body, except the lungs, and, perhaps, the depurative organs, that is more richly supplied with blood capillaries—certainly a most anomalous arrangement, if the striated muscle cells are entirely devoid of living matter, which alone of all things in nature is capable of being nourished.

Again, the statement by Dr. Beale, namely, "This contractile fiber, perhaps, consists of a passive basic substance of a fibrous character, through which is diffused a soft material, prone to move in directions at right angles to one another, according to the manner in which external forces operate upon it," and again, "The changing substance upon which the alteration depends can be expressed from the muscular tissue, and coagulates spontaneously like the fibrin of blood," is certainly very strong corroborative evidence of its bioplastic nature, since he has conclusively shown that "it is upon this material (bioplasm) that the coagulable property of the blood is mainly dependent, and it is this which, in great part, undergoes conversion into what we call fibrin when the blood is removed from the living vessels, or dies.

It is evident, then, that the material which is susceptible of being expressed from muscular tissue, and which has the property of undergoing spontaneous coagulation, thus being transformed into fibrin, cannot be other than living matter. It is susceptible of

being deeply colored with the carmine-staining fluid after expression, and no doubt it could just as readily be discriminated in this way, *in situ*, had not the formed material, of which the cell wall is composed, an *alkaline reaction.*

But, be this as it may, its nature is made evident; and as it is hardly probable that the bioplasm should, contrary to the universal rule elsewhere, be diffused throughout the substance of striated muscle, it follows, as a logical sequence, that it is collected in minute particles in an interior space in the anatomical structure of each cell.

Experimental histologists have shown that the irritant qualities of both acid and alkaline solutions, when caused gradually to come in contact with ciliated epithelium, instantly excite the slowly moving cilia, and cause them to "vigorously lash the liquid into which they project; but the effect is soon exhausted, for the alkaline liquid penetrating the cells destroys their vitality, and the motion of their cilia stops beyond recovery." These agents have the property of exciting muscular contractions also, so long as they retain their irritability; but the experiment proves fatal to a repetition of the phenomenon, as in the case just cited, and, as I take it, for precisely the same reason. It is generally conceded that the cilia vibrate in obedience to the confined or limited movements of the contained bioplasm. Analogy teaches us that the phenomena of muscular contractions are due to the presence of, and changes in, living matter within an interior space in the formed material of the striated as well as the non-striated muscle cells.

We might adduce much more testimony of the same character in support of the anatomical constitution of the striated muscle cell, such as I have described, but, as we are in possession of evidence of a different nature, but of like import, it will be best, perhaps, to take up the latter.

Physiologists tell us that the "*irritability of muscle* depends directly upon its anatomical structure and constitution," and for that reason "muscular irritability lasts longer after death in cold-blooded than in the warm-blooded animals." Now, every one at all familiar with the use of the microscope knows full well that it can be, and has frequently been, ocularly demonstrated that the bioplasm of a cold-blooded animal will live for hours, and in some cases even for

a day, at a temperature so low that the bioplasm of man would almost instantly cease its vital movements, assume the spherical form, and, unless the conditions suitable to its continued vital existence are quickly rendered more favorable, die. Seeing, therefore, that all muscular tissue which is actually dead is equally prone to undergo regressive changes, and that the conditions which are unfavorable to putrefaction, namely, a low temperature, are the very conditions which most frequently prove destructive of human bioplasm and of muscular irritability, after coordinate vitality has ceased, while under precisely the same atmospheric influences the cold-blooded animals retain their muscular irritability, we are led to believe that this difference is wholly dependent upon a difference in the power or capacity of different kinds of living matter to withstand adverse influences and the difference in the surrounding circumstances under which they normally exist. "These differences cannot, therefore, be attributed to the properties of the elements, to physical forces, chemical affinities, or to characters which we can ascertain or estimate by physical examination; but they must be referred to a difference in power which is inherited from pre-existing bioplasm, which we cannot isolate, but which it would be quite unreasonable to ignore."

Reasoning *a priori*, then, we are again forced to adopt the view that the striated muscle cells do contain living matter within their anatomical structure, and that it is by virtue of its vital existence that muscular tissue retains the property of responding to various external influences for an indefinite period after respiration and circulation have ceased.

Moreover, we are able to bring ocular proof of the presence of bioplasm within the cells of striated muscle as well as within those of smooth muscle.

Before doing so, however, it will be best to show that the living matter therein contained can and does act in such a way as to not only produce muscular contractions, but also that they experience such changes on the withdrawal of the exciting influence as will permit the muscle to return to its former state.

The striated muscle cells are found by actual measurement to be at least one-third more, and often greater still, in their longitudinal diameter than they are in their transverse diameter: it follows, there-

fore, that if the bioplasm within these cells can be caused to assume, or even approximate, the spherical form, the cells will necessarily be somewhat abridged in the direction of their greatest length and at the same time increased in their transverse diameter. The aggregate result of such a change will be just what occurs during the act of muscular contraction.

That these cells do possess an individual activity, that each cell does approximate the spherical form, and that too, independently of every other cell at the time of muscular contraction, is evident from the bead-like appearance which they then present.

You are all conversant with the fact, no doubt, that the *amœba*, the white blood corpuscle, yea, every and all kinds of bioplasm of which we have any practical knowledge, may be seen, even when in active movement, to instantly assume the spherical form when brought under the influence of the electrical current. Muscle quickly and forcibly contracts under the same influence, provided it has not lost its irritability.

If the proper precaution be taken, the experiment may be repeated a number of times, with perhaps the result of materially abridging the period of their vital existence. So may it, also, be repeated, in like manner, in the case of muscle, with constantly decreasing responsive power, until at last it becomes rigid in death.

Carbonic acid gas excites the naked bioplasts to more vigorous movements; but this soon ceases, however, and they assume the spherical form, and thus remain until putrefaction sets in, unless the precaution be taken to displace the CO^2 by substituting oxygen, as soon as the spherical form has been obtained. It induces exceedingly strong and vigorous contraction of the muscles, and is a favorite agent with many practitioners for the purpose of inducing premature action of the pregnant uterus. It is essential to a repetition of the experiment that the same precautions be taken as above.

Many agents possess the property of exciting naked bioplasm to assume the spherical form; and, indeed, this invariably happens during the transition from active life into the stillness of death, and, no doubt, because in this form less of their substance is exposed to adverse influences, and hence more of their substance is protected by the outer condensed portion. It is by virtue of this principle that germinal matter is often enabled to maintain a vital, though

quiescent existence, for months, and even years, when separated from its source of nutrient supply.

In every instance in which these agents have been tested, they have proved equally efficacious in exciting muscular contractions.

Finally, Schäfer in his work on Practical Histology says: "But if any object which possesses the property of refracting light doubly is placed upon the stage of the microscope and examined, and if then the field is made dark by turning the analyzer, it will be found that the doubly refracting substance remains bright, unless it happens so to lie that its optic axis is parallel with the plane of polarization of either nicol. And if the object be a muscular fiber at rest, the whole fiber will appear bright and doubly refracting; whereas if it be in a state of contraction the bright stripes only will allow the light to pass, the dark stripes in this condition of the fiber being singly refracting. Transversely striated muscle is not by any means the only tissue which is doubly refracting, for the property is possessed by the white fibrils of connective tissue, and by bone, as well as by the plain muscular fiber cells. But it is the only one which under certain conditions exhibit alternate bands of singly and doubly refracting substance. It has, however, been pointed out by Ranvier, that it is rather the condition of growth and formation of a tissue than difference of structure which tend to determine differences in the optical properties of the substance of which it may be composed. And he instances the case of cartilage, the matrix of which, although undoubtedly composed of the same substance throughout, is doubly refracting in those parts where the cells, either from pressure or in progress of growth have come to assume either a flattened or an elongated shape, singly refracting where they remain round."

The cartilage cell, as is well known, is purely and simply a mass of living matter imbedded in a space hollowed out, so to speak, in the matrix; and hence it follows that the difference in refractive property is entirely dependent upon the difference in form which this matter has come to assume.

If, then, we compare the appearances observed in cartilage with the phenomena of polarized light in which we find that the striated muscle cells are doubly refracting when the fiber is at rest, and consequently the bioplasts elongated, singly refracting when the muscle

is contracted and hence the bioplasts spherical in form, and that the bright stripes in the latter state coincide with the points of union of the cells, end to end, the dark stripes with the centrally located spherical bioplasts; and when we consider that this is in no wise dependent upon a difference in "anatomical structure or constitution," but wholly upon the peculiar formation, *i. e.*, the operation "of shaping and giving form," I think we are clearly justified in stating that we have optical proof of both propositions advanced by us.

By assigning to the cell.wall flexible properties, and allowing the bioplasts to passively resume their elongated form on the withdrawal of the exciting influence, we are able to explain how muscular tissue becomes relaxed after having been contracted, and, also, why the former is properly the state of rest.

This theory furnishes us a rational explanation for the difference which obtains between the two kinds of muscular tissue in the length of time which they respectively require to perform their contractile function; for the rod-shaped bioplast of the smooth muscle cell must necessarily travel over a much greater space in order to approximate the spherical form than is the case with the striated muscle cells. And, again, if the question were asked, Why, both being doubly refracting when at rest, the former remains doubly refracting throughout, while the latter becomes singly refracting at certain points, when they become contracted? we would answer, that the first is so constituted that its rod-shaped bioplast cannot do more than approximate the spherical form.

If the question should be asked, Why does muscle retain the property of contractility for an indefinite time after coördinate vitality has ceased? we should say, In consequence of there yet re-remaining in the immediate neighborhood of the contained bioplasm sufficient pabulum to nourish it yet a little while longer.

Taylor, in his work on Medical Jurisprudence, states that "in a case of death from Asiatic cholera Mr. Bumsey observed that half an hour after the complete cessation of respiration and circulation the muscles of the arms underwent, spontaneously, various motions of contraction and relaxation, continuing for upwards of an hour, and that, although previously cold, they then became evidently warmer." He says: "The restoration of warmth after the body has become cold, in such cases, can only be explained by supposing

that there still remains about it some lingering trace of vital action, although this may not be indicated by the presence of the ordinary signs of active life."

It is evident that the non-living formed material of an organism cannot manifest any evidence of vitality, except as it is acted upon by living matter; it follows, therefore, that whatever trace of vital action may still linger in the muscle is due to change taking place in bioplasm. It is because the bioplasm is living and eating and forming, that the temperature becomes elevated in such cases; or, to be more explicit, during nutritive and formative changes, during the conversion of pabulum into bioplasm, and also the latter into formed material, condensation takes place, and condensation here, as elsewhere, always takes place at the expense of an atmosphere of heat, which thus becomes manifest.

The question presents itself, What produces cadaveric rigidity? In every instance in which I have examined bioplasm in the last stage of its vital existence (and these observations have been numerous), they have invariably assumed the spherical form, and thus remained until regressive changes had supervened. The bioplasm of muscle, in accordance with the laws of analogy and with the facts above presented, proves no exception to this rule.

Finally, the question may be asked, "Why, the greater the degree of muscular irritability at the time of death, the later cadaveric rigidity sets in, and the longer it lasts, and the later also putrefaction appears, and the more slowly it progresses"?

Certainly not in consequence of any difference in anatomical structure or constitution, but because muscular "*irritability*" so-called, is directly dependent upon the presence of living, healthy (not shriveled), well-nourished bioplasm, as is clearly evinced by the fact that "the bodies of soldiers killed in the early part of a battle become rigid slowly, while those bodies killed at the close, or after many hours of muscular exertion, become rigid almost immediately." And, secondly, this latter fact shows that, in consequence of the pabulum having been exhausted, the bioplasm soon passes into and through the transition change; while in the former case, there yet remaining an abundant supply of nutrient material, the bioplasts are larger, more vigorous, able to maintain their vital existence longer, and are therefore better able to resist adverse influences, die harder,

and consequently resist putrefaction longer. So soon as the bioplasts have become completely devitalized, they passively obey the resilient influences of the cell walls, which yet retain their flexible properties, and hence the muscular system always becomes completely relaxed in death.

And now, in conclusion, the old adage, "Eating the pudding is proof thereof," is as true here as elsewhere; and hence if we fail to satisfactorily explain every known fact in connection with the diverse phenomena of muscular movements, either during the continuance of co-ordinate vitality, or after respiration and circulation have ceased, we will willingly consign our theory to the fate which has swept multitudes of theories into utter oblivion.

EXPLANATION OF PLATE I.

Fig. 1 represents non-striated muscle fibrillæ composed of cells of fusiform shape, enclosing bioplasm, *B*. The bioplasm approximates the spherical form and represents its state during the act of contraction.

Fig. 4 represents the same at rest where the bioplasm *B'* is seen to be elongated. It will be noticed that in the first the cells are shortened longitudinally, and in the last that they are the reverse.

Figs. 2 and 3 represent transverse sections of several non-striated muscle cells; some showing bioplasm, others being cut above or below the center of the cells.

Fig. 5 shows a fibrillæ of striated muscle in a state of contraction. The bioplasm *B* has assumed a spherical form, and the cells are shortened in their long diameter and increased in their transverse diameter. The nutrient matter *N* flows more abundantly to the cells.

Fig. 7 represents the same as Fig. 5, at rest, where the bioplasm *B'* has assumed its elongated form or state of rest.

Fig. 6 is a transverse section of same.

In all the figures the letters stand for same parts, thus:

B. Bioplasm in state of contraction.
B'. Bioplasm in state of rest.
F. Formed material.
N. Nutrient matter.
T. Tendon.

PLATE I.

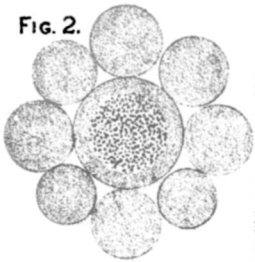

Fig. 2.

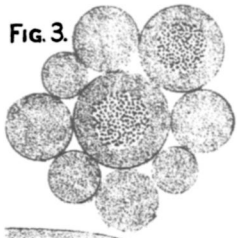

Fig. 3.

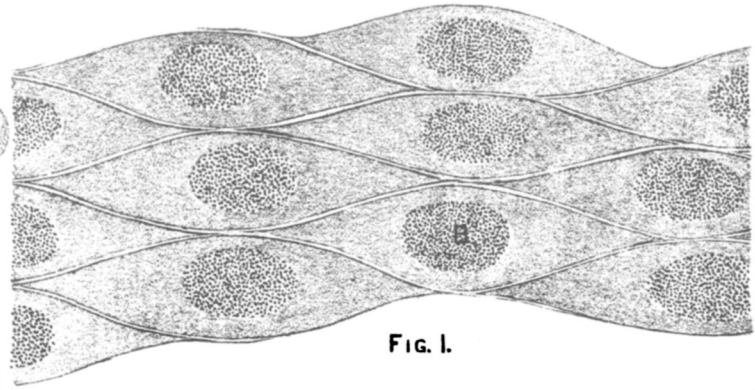

Fig. 1.

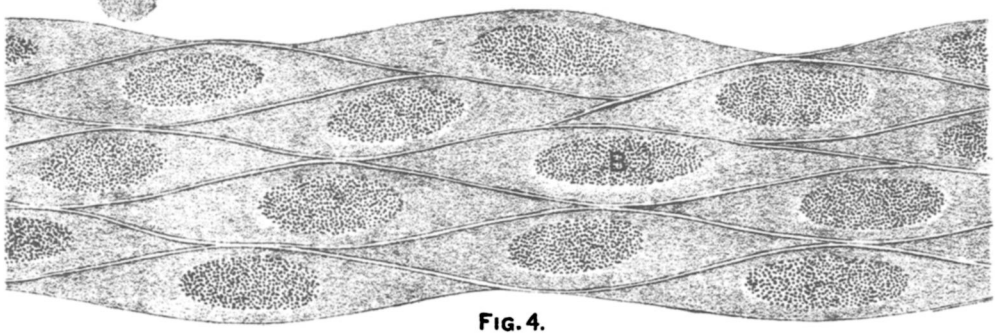

Fig. 4.

Fig. 6 - a

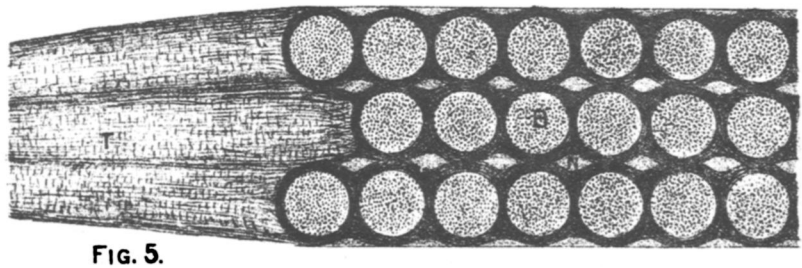

Fig. 5.

Fig 6 - b.